Worldwide Progress in Vehicle Technology and Emissions Norms
Leaders and Laggards Need To Move Fast

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Automobiles and the Environment

- Global Environment
- Urban Environment
- Emissions: CO₂, BC, O₃, VOC, NOₓ, PM
- Alternative Fuels
- Energy Security
- Convenience
- Recycle
- Economy
- Safety
Historical High Growth Has Resulted In Vehicles Being Important Contributor To Local, Regional and Global Pollution

Figure: World Motor Vehicle Population

- Motorcycles
- Commercial Vehicles
- Cars

Calendar Year


Millions

0 500 1000 1500
Figure: Annual Production of Cars, Trucks and Buses

R squared = 0.886
EPA Emissions Standards for Diesel Trucks

PM (g/hp-hr) vs. NOx (g/hp-hr)

- 2007-2010
- 1990
- 1991
- 1994
- 1998
- 1991
- 1988
- unregulated
U.S. and Euro Light-Duty Vehicle Emission Standards

Note: U.S. Tier 2, Bin 5 is equivalent to CARB LEV II - LEV

- Gasoline NOx
- Diesel NOx
- Diesel PM X 10

mg/km

50 ppm S cap

Euro 4
- 2005: 80
- 2009: 250
- 2014: 250

Euro 5
- 2009: 60
- 2014: 180

Euro 6
- 2009: 60
- 2014: 80

U.S. Tier 2, Bin 5
- 2009: 45
- 2014: 43

EPA/CARB
- 2009: 43
- 2014: 62

Euro 5+ (2011) and 6 include $6 \times 10^{11}$/km diesel particle number limit;
Euro 6c includes PN limit for GDI
U.S. and Europe: Heavy-Duty Primary Exhaust Emission Control Technologies

- **2005, 2008, 2013**
- **g/kWh**
- **50 ppm S cap**
- **10 ppm S cap**
- **15 ppm S cap**

**Graph Details:**
- **Y-axis:** g/kWh
- **X-axis:** European and US standards
- **Technologies:**
  - SCR
  - SCR (EGR+DOC options also)
  - EGR + DOC + DPF + SCR
  - EGR + DOC + DPF

**Legend:**
- **Yellow bar:** Diesel NOx
- **Red bar:** Diesel PM X 100
Diesel Particulate Filters (DPFs)

- Wall flow ceramic filter element with high capture efficiency for particulates over a broad size range (cordierite or SiC filter elements)
- Captured soot needs to be burned off (regenerated) at regular intervals to manage backpressure on engine
- Commercialized on light-duty diesels in Europe in 2000, on US LDD starting in 2006; standard on US 2007+ trucks/buses, on 2013+ Euro VI trucks/buses – 10s of millions in-use worldwide
- Capture soot and inorganic-based particles associated with engine wear, lubricant consumption: regular maintenance required (filter cleaning)
Distribution of Controls
Light Duty Diesel Vehicles

2015
- Engine Mods: 2.2%
- Tier 2: 8.6%
- Euro 2: 1.6%
- Euro 4: 15.7%
- Euro 5: 15.1%
- Euro 6: 56.8%

2025
- Engine Mods: 3.7%
- LEV3: 8.8%
- Euro 4: 5.0%
- Euro 5: 3.4%
- Euro 6: 79.1%

2030
- LEV3: 8.0%
- Engine Mods: 3.4%
- Euro 4: 2.7%
- Euro 6: 85.9%
Distribution of Controls
Heavy Duty Diesel Vehicles

2,015
- US10: 12.3%
- Euro 6: 12.6%
- Euro 5: 5.0%
- Euro 4: 48.2%
- Eng Mods: 11.8%

2,025
- US10: 9.2%
- Euro 6: 9.5%
- Euro 5: 3.1%
- Euro 4: 9.5%
- Eng Mods: 13.9%

2,030
- US10: 12.0%
- Euro 4: 8.4%
- Euro 6: 70.7%
- Eng Mods: 8.9%
Diesel Engine Compliance Program

- **Engine Design and Build**
  - Manufacturer Prototype and Durability Testing

- **EPA Action**
  - EPA Issues Certificate of Conformity
  - EPA Confirmatory Testing
  - EPA Review of Manufacturer Application

- **Manufacturer Action**
  - Engine May Enter Commerce

- **Full Useful Life**: On-highway: up to 10 years / 435,000 miles
  - Nonroad: up to 10 years / 8,000 hours
  - Marine: up to 10 years / 20,000 hours
  - Locomotive: up to 10 years / 32,000 MW-hours
Clean Diesel Vehicles Include Sophisticated Sensors and Diagnostics

- Combined $O_2$/NOx Sensor
- Ammonia Sensor
- Soot Sensor
- Urea Quality Sensor
- Diagnostic Systems
- Heated Urea Tanks
U.S. 2007 HD Emission Performance Provides Significant Reductions in PM, CO, Air Toxic HCs

<table>
<thead>
<tr>
<th>Compounds</th>
<th>% Lower Than 2004 Engine Technology</th>
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<tbody>
<tr>
<td></td>
<td>16-Hour Cycle</td>
</tr>
<tr>
<td>Single Ring Aromatics</td>
<td>82%</td>
</tr>
<tr>
<td>PAH</td>
<td>79%</td>
</tr>
<tr>
<td>Nitro-PAH</td>
<td>81%</td>
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<tr>
<td>Alkanes</td>
<td>85%</td>
</tr>
<tr>
<td>Polar</td>
<td>81%</td>
</tr>
<tr>
<td>Hopanes/Steranes</td>
<td>99%</td>
</tr>
<tr>
<td>Carbonyls</td>
<td>98%</td>
</tr>
<tr>
<td>Inorganic Ions</td>
<td>38%</td>
</tr>
<tr>
<td>Metals and Elements</td>
<td>98%</td>
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<tr>
<td>Organic Carbon</td>
<td>96%</td>
</tr>
<tr>
<td>Elemental Carbon</td>
<td>99%</td>
</tr>
<tr>
<td>Dioxins/Furans(^a)</td>
<td>99%</td>
</tr>
</tbody>
</table>

\(^a\) Average value between 2007 and 2009, with full enforcement in 2010 at 0.20 g/hp-hr

Source: CRC Phase 1 ACES Report; 2010+ Engines Delivering Even Lower Toxic HC Emissions than 2007 Engines
Developments for Euro 1 – Euro 5

Fig. 4. Mean hot NOx emission factors of gasoline (left) and diesel (right) passenger cars and light commercial vehicles as a function of model year. Whiskers represent the 95% confidence interval over the mean. Added are the type approval limit values for Euro 1 to Euro 5 passenger cars over the homologation test cycle in force in the respective year. For conversion from limit values in g per km see SI (using measured fuel consumption rates from Hausberger (2010)). For color plot consult online version.

What About Trucks?
The problem: High off-cycle NOx emissions in urban applications

In-use PEMS testing of Euro IV and Euro V trucks in The Netherlands found emission well above standard in urban driving in 2008!

Source: Kleinebrahm 2008
California’s Low-Emission Vehicle Program

- Adopted in 2012
- Achieves 75% reduction in smog-forming pollution
- Achieves 90% reduction in PM standard

Particulate Matter Emission Limits (milligrams/mile)

- Current Standard: 10
- 2017-2022: 3
- 2025-2028: 1

NMOG + NOx (grams/mile)

Cars
Proposed Optional Low NOx Engine Emission Standards for MY 2015+

<table>
<thead>
<tr>
<th>NOx Level g/bhp-hr</th>
<th>% Below Current Standard</th>
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<tbody>
<tr>
<td>0.2 (Current)</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>- 50%</td>
</tr>
<tr>
<td>0.05</td>
<td>- 75%</td>
</tr>
<tr>
<td>0.02</td>
<td>- 90%</td>
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</tbody>
</table>
Zeolite SCR Catalysts Developed for Mobile Source Applications with Broad Temperature Windows and Good Thermal Stability

Aged 650°C, 100 Hours; Tested at 100k SV

Cu Based SCR Improvements

SCR catalysts aged 50 hours at 700°C
Clean Diesel Technology Driven By a Decade of U.S. EPA Mobile Source Emission Regulations

Average Benefit:Cost = 20:1

Tier 2 Light-Duty
final rule 1999
fully phased in 2009
Diesels held to same standards as gasoline vehicles
Diesel sulfur now 15 ppm

Ocean-going Vessels
final rule 2009; IMO ECA in 2010
ECA: 1000 ppm Sulfur in 2015;
80% lower NOx by 2016

Heavy-Duty Highway
final rule 2000
Sulfur now 15 ppm
fully phased in 2007-2010

Locomotive / Marine Tier 4
final rule 2008
Sulfur now 15 ppm
fully phased in 2017

Nonroad Diesel Tier 4
final rule 2004
Sulfur now 15 ppm
fully phased in 2015
Significant On-Road Retrofit Experience, Off-Road Experience Growing

- >300,000 on-road DPF retrofits and >50,000 off-road DPF retrofits worldwide; > 100,000 DPF retrofits in the U.S.
- >1 million DOC retrofits worldwide
- Significant experience with retrofit technologies exists for on-road vehicles
  - School buses, transit buses, long- and short-haul trucks, refuse haulers, utility vehicles
- Retrofit experience is growing for many off-road applications
  - Construction equipment
  - Port vehicles/equipment
  - Marine engines and locomotives
  - Stationary internal combustion engines used for power generation
Technical Considerations for Successful Retrofit Projects

• Vehicle should be properly maintained before considering retrofit
• Application engineering – Matching the right technology to the specific piece of equipment and application
• Proper professional installation – Retrofits can be installed safely (visibility concerns addressed)
• On-vehicle monitors – Provide important user feedback on performance (don’t ignore warning lights)
• Maintenance – Vehicle/equipment and retrofit device require inspection and maintenance

Successful Retrofits Require a Cooperative Effort Between Fleet Owners, Operators, and Technology Providers
India covered a lot of ground from 2001-2010, but is falling behind now

- For 2/3 wheelers:
  - HC+NOx combined standards;
  - Poor durability
  - No evaporative emission standards

- For Light-Duty Vehicles:
  - Diesel car share has increased to 50% of new vehicle sales in FY 2012-2013
    - Euro IV diesels emit three times NOx and an order of magnitude higher PM emissions than Euro IV petrol
    - Little progress on refueling evaporative emissions

- For Commercial Vehicles and Buses:
  - BS IV limited to a few bus fleets, trucks still at BS III
Auto Fuels Policy Committee
Vision

• Fuels Road Map
  • BS IV Fuels (50 PPM) Phased in Across Entire Country by 1 April 2017
  • BS V Fuels (10 PPM) Phased in Across Entire Country by 1 April 2020

• Vehicle Emissions Road Map
  • BS IV Nationwide in 2017
  • BS V for New Models from 1 April 2020 and all Models by March 31 2021
  • BS VI Four Years after BS V (1 April 2024)
Our Recommendations

• Enhance and then Adopt Recommendations From Committee on Auto Fuel Vision and Policy
  – Skip Euro 5/V and go directly to Euro 6/VI
  – Add ORVR and Zero Evaporative Emissions.

• Replace current test cycles with world-harmonized test cycles for all vehicle types.

• Ministry of Petroleum and Natural Gas should establish national fuel testing program at retail outlets

• Ministry of Road Transport and Highways should establish national in-use vehicle testing
Advantages of Euro 6/VI Over Euro 5/V

• Tighter Standards
• New and Improved Test Procedures Provide More Comprehensive Coverage of Range of Real World Driving Conditions
• Actual In Use Focus (RDE)
• Improved Onboard Diagnostics
• Likely Gasoline Particle Filter
Thank You